INTRODUCTION

THE SALINE SOLUTION—AN INNER SEA

There is another sea, a dark red ocean of blood filled with monsters no less threatening than a shark or venomous blue-ringed octopus. For the majority of humans on the Earth, this inner sea is populated with dangerous beasts—parasites. They suck the blood from the outside or use it as a habitat, drawing sustenance from the human body and wringing from it life-sustaining forces that they pervert to their own needs.

Parasites can flow with the blood to take haven in the richly oxygenated lungs, suckling on the inside of the breast rather than the outside, to prepare themselves for a lifetime of harm to the host. Some have adapted to take advantage of this pulmonary paradise to go through their developmental stages, a hiatus permitting ever more adaptive efficiency on the road toward the creation of the *perfect parasite*. Perfection is not necessarily physical—it can be physiological or biochemical. The tapeworm, lacking a mouth, an intestine, or an anus of its own, appears to be an unprepossessing piece of segmented linguini. But its outer covering is feathered into microscopic microvilli, making the surface fuzzy like a blotter, able to differentially soak up molecules of nutrients. It lives in the small intestine. There it is bathed in a river of fluid composed of chewed up chunks of lunch mixed with digestive juices to make a rich soup containing enzymes that chemically shred

molecules of food into their constituent building blocks. The Whopper you ate is reduced into amino acids by your proteolytic enzymes. *But the tapeworm is made of proteins*—how is it not digested with the food? Not only does the multifunctional surface facilitate the passage of nutrients into its body, but it also prevents proteolytic enzymes from destroying it by producing an antienzyme.

Many parasitic nematodes (roundworms) spend time in the lungs, growing and changing, like the pupae of butterflies. Once mature, they leave their nursery and drift in the blood to their final destination: the intestines, the lungs, lymph spaces of the groin, or under the skin. The story is told of a British expatriate who, at the end of a long tenure in Sudan, returned home to the traditional retirement destination, the hallowed ivy-covered cottage in Surrey. Every day, precisely at teatime, a tiny worm would swim across his cornea, visible to his guests. He became quite the popular host. The worm was *Loa loa*, a sometimes benign relative of the filarial worm that causes the grotesquely deformed legs and testicles characteristic of elephantiasis.

But why did this worm appear precisely at 4 p.m. every day? Why was the worm on a timetable like a railroad? Forty years of conjecture have yielded this explanation: The man's blood was thinned by years of living in the blinding heat of Sudan. Consequently, he must have lit the fireplace at teatime to take the chill out. The warmth of the fire absorbed by his skin must have brought subcutaneous worms close to the surface. They undulated under the skin, through the sclera and across the cornea of the eye. That's the best I can do to explain the mystery!

RELATIONSHIPS

Relationships are invariably complex. An intimate long-term attachment can suddenly go awry; one partner can turn on the other, with dire consequences. Often, over time, the dependent becomes the dominant. Sometimes the relationship becomes so all-encompassing that one member is almost subsumed by the other. Separation is rampant as youthful indiscretions cause breakups. Often, to everyone's surprise, one member discovers he/she has a penchant for members of the same sex. Often the discovery is made when a partner becomes a flamboyant cross-dresser.

Am I talking about people? No. The following stories are gossip not about humans, but about animals that live together "for better or for worse." Some have long-term interdependencies, and their mutual survival depends on the interaction. Some relationships are ephemeral, and one or another partner can wander off at any time, both being capable of independent living. Sometimes one member gets something from the other but does not apparently contribute anything to the partner's well-being—the stay-at-home parent, for example.

Sometimes one partner hurts the other.

Relationships can change. If one animal receives shelter from another, the interaction might be commensalism (one partner benefits while not harming the other). But careful observation of the partners over time can reveal that the apparent beneficiary betrays its protective host by biting chunks of tissue from its living haven. In a Jekyll-Hyde switch, the commensal changes into a parasite.

Hypothetically, there is a sequence of developmental stages leading to the dazzling complexity of the host-parasite relationship. First, an accidental association. Then a progression to the ultimate intimacy, one species taking sustenance from the other, to the host's detriment. But parasitism is not the only interactive evolutionary process—often there is a succession of less inclusive interactions between animals of different species. Symbiosis (living together) has three major categories—mutualism, commensalism, and parasitism. To oversimplify:*

Mutualism (formerly called symbiosis) is an interaction between two organisms, each of a different species, both of whom benefit.

Commensals derive something out of the relationship but do not harm the host.

Parasites harm the host.

MUTUALISM

Mutualistic relationships are likely to be ancient and long term since each participant has had to evolve mechanisms not only for its own benefit, but for its partner's. Corals, living in seas virtually devoid of food (plankton), cannot survive without hosting plantlike one-celled

* For more accurate definitions, see the glossary.

organisms, zooxanthellae, in their tissues. The zooxanthellae are able to perform photosynthesis to produce food, shared with the coral partner. The coral, in turn, contributes its waste, carbon dioxide, to the zooxanthellae, which they use to manufacture extra food, making it possible for *them* to survive.

The zooxanthellae benefit further—the corals protect them. The corals get another benefit as well: the extra energy provided by their zooxanthellae makes it possible for the corals to extract calcium carbonate from the water to manufacture their famed chalklike skeletons. How's that for complex interdependence?

Similarly, the cleaning goby, *Labroides dimitiatus*, gets exclusive permission to graze in a flourishing field of parasites on the body of its fishy partner, who benefits by being relieved of its tissue-eating and bloodsucking burden.

COMMENSALISM

One partner benefits from the relationship and the other neither benefits nor is harmed. Commensalism means "to eat at the same table." The remora clings to the belly of the shark and feeds on the scraps of its meal. An ameba, *Entameba gingivalis*, lives in the human mouth. It inhabits the gum line, harmlessly eating bacteria between the teeth. It gets sustenance from its partner but has not become a parasite. Would it be beneficial for it to become a parasite? Why should it? The ameba lives happily in the mouth, protected by its human partner, not causing the slightest damage to its human haven. Is this not better than parasitism, where even minimal harm may ultimately impair the host, threatening the existence of the parasite?

PARASITISM

Parasite and host often evolve physiological accommodations to one another. The parasite acts to keep the host as healthy as possible while surreptitiously extracting the wherewithal to sustain its life. This is logical and intuitive. But more incomprehensible are the *behaviors* that lead to interactions between parasite and host. How did they evolve?

How do bird brood parasites figure out what nests to lay their eggs in? How do parasites develop behaviors parallel to their host's to allow them to insert their developmental stages at a particular time? The kentrogon larva of the barnacle, *Sacculina*, will die after a week of aimlessly searching if it cannot find the leg joint of a newly molted crab into which it injects is essence, stem cells that will develop into a cancerlike invader whose tendrils insidiously permeate the insides of the crab, keeping it alive until the last moment, like the monster in the movie *Alien*.

It is the evolution of parasite behavior that so fascinates.

All three relationships are found in abundance in nature. One might infer that less intimate interactions are precursors to more precise relationships between host and parasite. For example, a tiny white pinnotherid crab lives in the mantle cavity of a clam. It feeds on the mucous-entangled planktonic waste of the clam. But every once in a while, the crab takes a nip from the clam's mantle tissues. Is this part of a transition from commensalism to parasitism? Perhaps.

Every so often an exciting event occurs in the life of a parasitologist. A zebra in the local zoo died. The zookeepers had standing instructions to let us know of any deaths that occurred. While this was a sad event for them, it was a source of jubilation to our necrophiliac crowd. We arrived soon after the unfortunate event. Without further ado, someone whipped out a butcher knife and we began diving into the rumen (stomach chamber) of the newly dead zebra. It was filled with an almost infinite number of flagellated protozoans. Was this a sick animal, done in by intestinal parasites? No, the protozoans were mutualists; they helped digest the tough grass that the zebra ate and received a warm, moist, protective environment for their trouble. Yet closely related flagellated parasitic protozoans found in the human vagina and female reproductive system can cause irreparable harm.

There are many mysteries in the depths of the inner sea. We will discuss a few monsters of these bloody depths.